P-140

SECRET

PROGRESS REPORT NO. 10

Contract No. RD-53-SA
Research Order No. 1RD4

Prepared by: Project Engineer 50X1

Approved by: Chief Engineer 50X1

50X1

Submitted: December 28, 1954

Covering period from October 1, 1954 to November 6

Copy No. 3

SECRET

INTRODUCTION

This is the concluding report on research and development task 4. The characteristics of the various pulse communications systems studied for this task are summarized. A pulse duration modulated transmitter and receiver which was designed for this study is described.

Pulse modulation methods of securing privacy in communication from conventional AM and FM receivers are described. The operation of the pulse duration modulation equipment designed for the system is explained. The results of tests made on the system are tabulated. Circuit diagrams of the system complete with latest modifications are included.

DISCUSSION

Pulse communication systems are used commercially because they lend themselves to a method of multiplexing. This is determined from the Nyquist theory of information sampling. This theory states that it is not necessary to send a continuous signal to retain the intelligibility of a message. Samples of the signal are taken at regular intervals. The minimum rate of sampling is specified as twice the highest audio frequency to be reproduced.

Since there are time intervals between samples, it is possible to utilize this space to send a number of messages. Each message is sent along its own time channel. Pulse receivers separate the channels and reproduce the messages from the sampled information of each channel. This method of multiplexing is referred to as time division. In this way the entire period is utilized for transmission with the exception of small time intervals that act as guard bands between channels.

This unique multiplexing feature that is common to pulse systems is the basis for a method of attaining privacy in communication, as developed in this task.

Pulse Amplitude Modulation

PAM is a system whereby the amplitude of the pulse is varied by the modulating speech. Linear amplifiers are required throughout the system in order to avoid distortion of the pulse peaks. Another disadvantage arises from the fact that the information is borne on the peak of the pulse and noise rejection methods are not applicable. As a result, stronger signals are required at the receiver. This will be further clarified in the discussion of the remaining systems. PAM systems were described in reports #1 and #2.

Pulse Time Modulation

PTM involves a system of two pulses. The first pulse acts as a synchronizing or trigger source. The second pulse contains the intelligence. The audio modulating signal causes to vary the position in time of the pulse relative to its unmodulated time of occurrence. The pulses have a constant amplitude. This characteristic results in some advantages over the PAM system. Amplifiers can be operated non-linear and at maximum efficiency.

Also as a result of the constant amplitude feature, the receiver can be designed to work with a weak signal. Under this condition the transmitted pulse arrives at the receiver with noise riding the peak. To this is added the receiver noise, which also appears along the base line. As long as the negative peak of the noise level riding the pulse does not extend to meet the positive peaks of the base noise level, there will be a portion of the pulse edge that is free of noise. It is possible to clip both base and peak. This leaves a horizontal slice of pulse whose edges are free of noise. The pulse is then subject to further amplification. A complete PTM system was described in report #6.

Pulse Duration Modulation

PDM is a method of communication wherein the width of the pulse is varied in accordance with a modulating audio signal. Since a constant amplitude pulse is used, the same advantages of efficient amplifiers, and peak and base clipping at the receiver, apply to this system as described for PTM.

Although the duty cycle was not as favorable as the PTM system, the transmitter circuitry was much simpler. The PTM system consists of a basic PDM pulse which is put through a process of differentiation, clipping and amplifying to derive a PTM signal. As a consequence, the PDM transmitter required fewer stages, and the system lent itself to miniaturization more readily.

A method of privacy in pulse communication was developed involving the control of the index of modulation. If the modulation is maintained at a very low level, the major portion of the pulse energy represents the pulse repetition frequency. This pulse frequency appears at an AM and FM receiver as a loud squeal compared to the amplitude of the audio signal. This squeal tends to mask the intelligence.

If the level of modulation is increased beyond a preset level, the signal is intelligible through the pulse squeal. An advanced method used to insure complete privacy at any modulation level involves the use of a noise masking technique. The intelligence is transmitted along with a strong noise signal. The theory underlining masking requires that the frequency of the masking note, be the same as or slightly lower than, the note to be masked. The signal to be masked in this case is the entire speech trequency spectrum. By the use of white noise as the masking device, the entire range can be covered. The ratios of signal to masking noise required for various degrees of masking are detailed in the testing section.

DESIGN OF EQUIPMENT

A radio link was designed and added to the pulse duration modulator and demodulator circuit described in report #9.

Transmitter

In the transmitter, figure 1, two methods of modulating the crystal controlled RF amplifier were considered, plate and grid modulation. Plate modulation was discarded when the pulse shape was distorted in the plate coupling transformer. A grid modulated 6c4 RF amplifier was used. The RF source is a 74 megacycles crystal controlled oscillator. The grid of the RF amplifier is biased to cut off by a variable -250 volt bias. The bias supply was made variable so that the RF output could be controlled in order to test the receiver under both weak and strong signal conditions. It was found that an optimum bias setting existed which would allow an undistorted pulse output. To prevent the output stage from self oscillating, the plate grid capacitance was neutralized. A plate voltage of 600 volts is used. This is the maximum voltage that can be used with the 6c4 tube under this duty cycle condition. However this could be increased with the use of other tubes. The output stage is transformer coupled to a transmission line that current feeds a telescoping Marconi antenna. The modulator is unchanged from the one shown in the previous report except for a 12AU7 amplifier stage that was added to amplify the pulse prior to gating the RF amplifier. The transmitter power supply was built into a compact unit which used no tubes. Both the main chassis with its telescoping antenna and the power supply chassis were able to fit into a standard size brief case. The transmitter could also have been powered by a suitable battery pack supply.'

Receiver

The receiver, figure 2, consists of a variable tuned oscillator and RF amplifier mixed in a triode, with an I.F. output of 23.5 megacycles. Seven stages of I. F. are used with the bias of the third and fourth stages variable in order to adjust the sensitivity. The signal is detected as a negative pulse in a germanium detector. The pulse is first amplified in two stages of amplification and then the base and peak is clipped in a 6AL5 stage. The pulse is again amplified before it is separated into two channels. One section goes through an amplifier and then a differentiator. The first positivespike, which is the leading edge of the first pulse, triggers a multivibrator whose pulse duration is such that when it is added to the original signals it cancels the first pulse and the noise modulated edge of the second pulse. The other section of signal goes through one stage of amplification to make it a negative pulse and is then added to the cancellation pulse at the mixer tube. The new pulse, which has a fixed leading edge and an audio signal modulated lagging edge, is fed through a base clipper, an amplifier, a peak clipper and a cathode follower. The pulse is fed through a low pass filter and an audio amplifier. It is then fed through two additional low pass filters and a power amplifier to the output transformer and speaker. The theory of the demodulator is the same as reported in the previous report except that the signal is first amplified before being clipped. This was found necessary for effective clipping under weak signal conditions.

The receiver was constructed with an internal power supply which provided the required operating voltages.

TESTING

The PDM unit was tested on a system basis. Tests were conducted both in the laboratory and under field conditions at a distance of 3 miles.

Frequency Response

The unit was designed to accommodate the speech frequency range. This was confirmed by an overall system frequency test. The frequency response at the 6 decibel points was 275 and 2500 cycles per second.

The transmitter was modulated through a crystal microphone. Male and female voice were reproduced with clarity under two sets of conditions, speaking directly into the microphone, and engaging in normal room conversation at different parts of the room. In each case the received signal was of high intelligibility.

Signal to Noise

Tests were conducted to determine the effectiveness of the peak and base clipping circuits. Under weak signal conditions, a signal that appeared at the detector output of the receiver with a signal to noise ratio of 3 to 1 was properly demodulated. These circuits were equally effective with and without noise masking transmission.

Privacy Without Masking

Another feature of pulse communication systems, as indicated in the discussion, was tested with interesting results. It was desired to ascertain to what degree privacy could be attained by a pulse system. This is based on the fact that the signal energy is a small percentage of the total energy as determined by the index of modulation. Most of the energy represents the pulse repetition frequency. Since the conventional receiver does not filter this frequency, the pulse appears as a loud squeal and tends to mask the intelligence.

The system was tested under two sets of conditions. One set of recordings refers to the minimum noticeable modulation. For this test the speech modulation wa gradually increased until it became audibly apparent that some communications was present. However, the signal was not intelligible. The modulation is recorded in percent, and the figure is derived as follows: the total pulse width was 34 microseconds. The first figure noted as minimum noticeable modulation on the PDM receiver was 0.4 microseconds deviation. This results in a percentage modulation of 0.4/34 or 1.17%.

A second set of test data was recorded under minimum recognizable modulation conditions. For this test the speech modulation was gradually increased until the communication was approximately 50% recognizable. At this point the signal was intelligible, and the message could be understood. An excellent reference on the relationship of percentage of recognition of a message to intelligibility is "Acoustic Measurement" by L. L. Beranek. The results are recorded as a percentage of the deviation caused by the signal modulation over the total pulse width of 34 microseconds.

	PDM	AM	FM
Minimum Noticeable Modulation	1.17	4.12	2.06
Minimum Recognizable Modulation	2.06	20.6	5.88

There is an obvious minimum advantage of the PDM receiver by a factor of 5.88/2.06 or 2.91. However, if it is desired to receive a recognizable signal on the PDM receiver, with no indication of the presence of a communication on the AM or FM receiver, critical adjustment of the index of modulation is required. The limiting factor on the minimum index of modulation is the signal to noise ratio for dependable reception. This in turn would be determined by the pulse rise time and local noise conditions at the receiver.

Nevertheless, it is believed that this approach to privacy in communications has possibilities. Various parameters, such as duty cycle, pulse width and pulse repetition frequency, should be investigated fully. This method of privacy would result in great simplification of circuitry, improvement of duty cycle, and transmitter efficiency.

Privacy With Noise Masking

Privacy tests were made using noise masking. The deviation resulting from the masking noise modulation was adjusted for 15 microseconds. The same two sets of conditions were recorded. The percentage of modulation was based on a pulse width of 34 microseconds.

	PDM	AM	FM
Minimum Noticeable Modulation	2.06	14.7	11.7
Minimum Recognizable Modulation	4.12	20.6	29.4

These figures are significant inasmuch as they summarize the entire principle of noise masking pulse signals. The minimum figure for recognition on a PDM receiver is 4.12% . The minimum figure that could be noticed on a conventional receiver is the 11.7% as determined by the F.M. receiver. As long as the signal percentage modulation remains between these two figures, the PDM reception will be adequate, and there will be no indication of the presence of speech on a conventional receiver. The only indication on the conventional receiver was the squeal representing the pulse repetition frequency. Thus it is seen that there is a factor of safety of 2.85 in the modulation percentage. In a similar manner if there is no need to avoid an indication of the presence of a signal, but only to mask the intelligence of the signal, the factor of safety becomes 29.4/4.12 or 7.15.

Another result of this masking test that is of great interest isthe ratio of masking noise to signal. The masking noise deviation was 15 microseconds.

	PDM	AM	FM
Minimum Noticeable Modulation	21.4	3	3.75
Minimum Recognizable Modulation	10.7	1	1.5

It can be seen that for AM reception of a recognizable signal, the signal must be equal to the noise. The FM receiver could work with a signal that was slightly smaller than noise by a factor of 1.5. The PDM receiver, which virtually eliminates the entire masking noise and pulse repetition frequency before the final audio stage, was able to work with a factor of 10.7.

Transmitter Power

The transmitter designed for these tests had an average RF power output of 1 watt. The duty cycle chosen for convenience of circuitry was 1:5.5. This resulted in a peak or pulsed power of 5.5 watts.

CONCLUSIONS

Three types of pulse communications systems were investigated. Pulse duration modulation was found to have various advantages over pulse amplitude and pulse time modulated systems. These included efficiency, simplicity of circuitry, compactness, reception of signals with low signal to noise ratios at the receiver and adaptability for a privacy system.

The PDM unit was designed to incorporate privacy against detection by a conventional AM or FM receiver. This was accomplished by means of a noise masking technique, wherein a white noise was transmitted whose amplitude was greater than the amplitude of the speech signal.

Field tests were also conducted to investigate the possibility of privacy without the use of noise masking. It was found that with carefully controlled low levels of signal modulation, the pulse repetition frequency squeal completely masked the signal at the AM and FM receiver, and still enabled adequate reception at the PDM receiver.

The system was tested under laboratory and field conditions. With noise masking the privacy was complete. There was no indication of any communication on the AM and FM receivers other than noise and the presence of the pulse repetition frequency squeal.

Tests were conducted under weak signal conditions to determine the effectiveness of the clipping circuits. The receiver functioned properly with a signal to noise ratio of 3 to 1.

Although extensive field tests were not conducted at the time of this writing, to determine transmitting range of the system, dependable communication was noted at a distance of 3 miles.

There was no effort made to miniaturize the equipment, nevertheless, the transmitter and power supply was compact enough to be carried in a standard size brief case.

SECRET

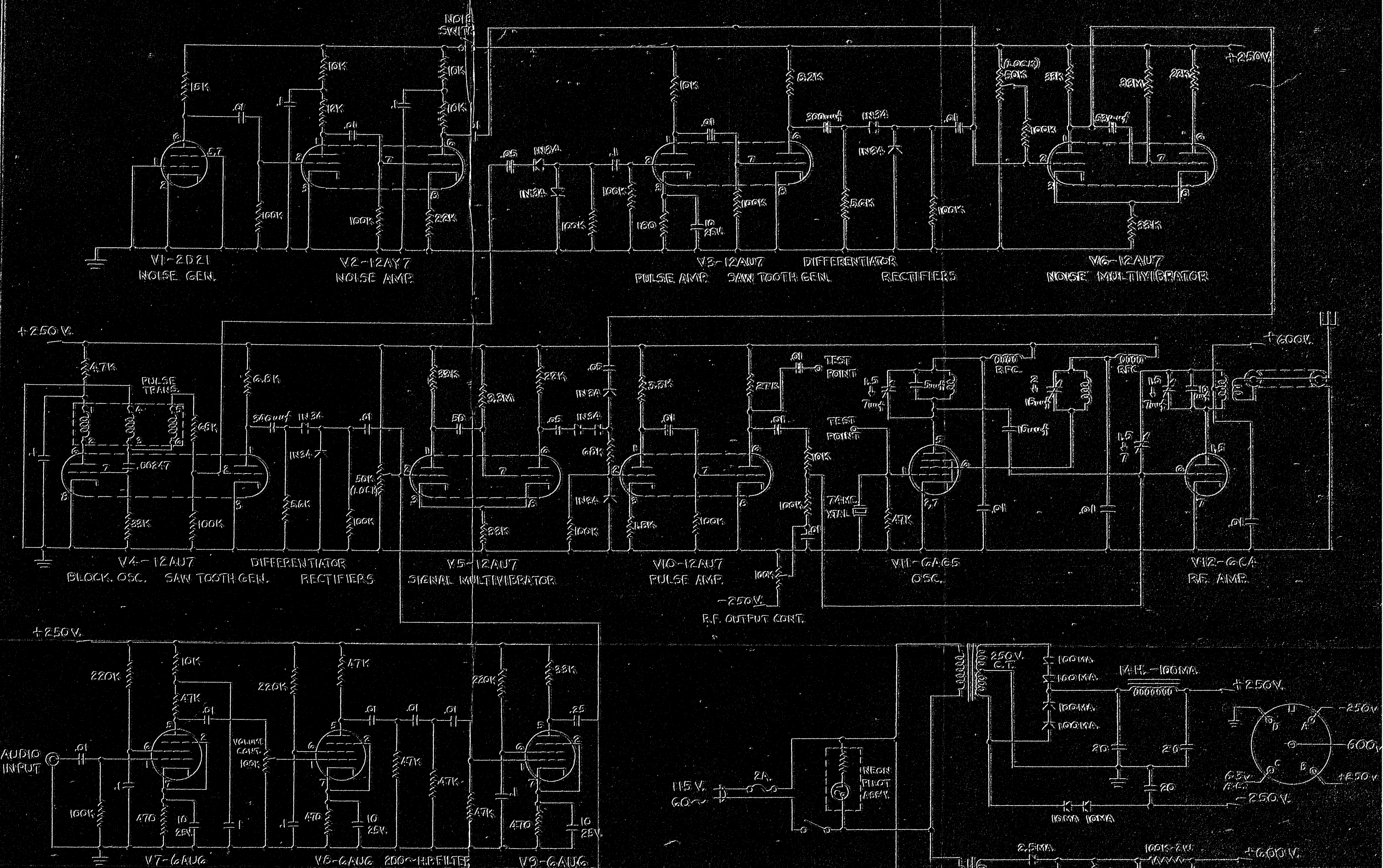


FIG.1 - PULSE DURATION MODULATED TRANSMITTER - NOISE MASKING

FIG. 1

SECRET

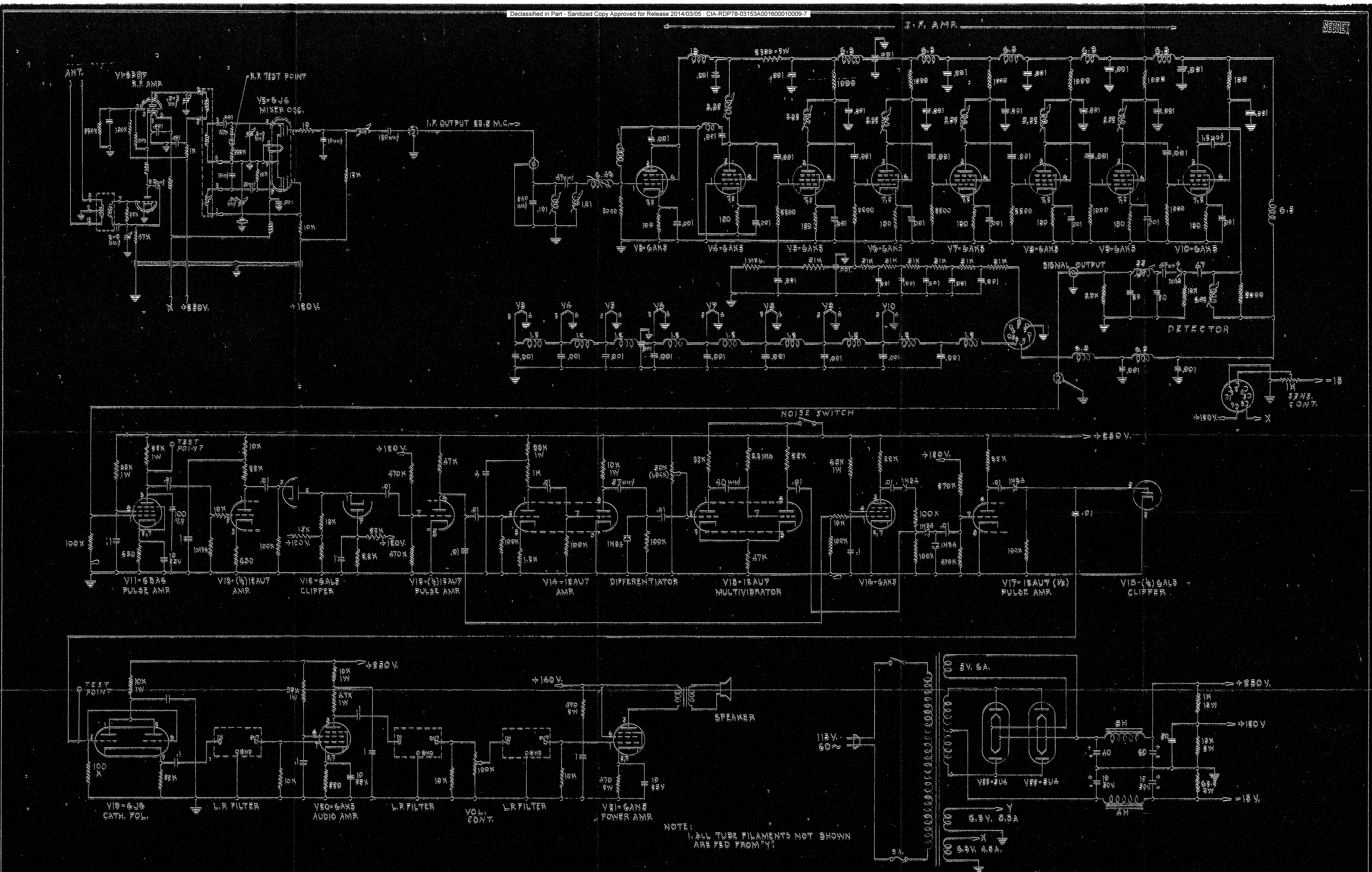
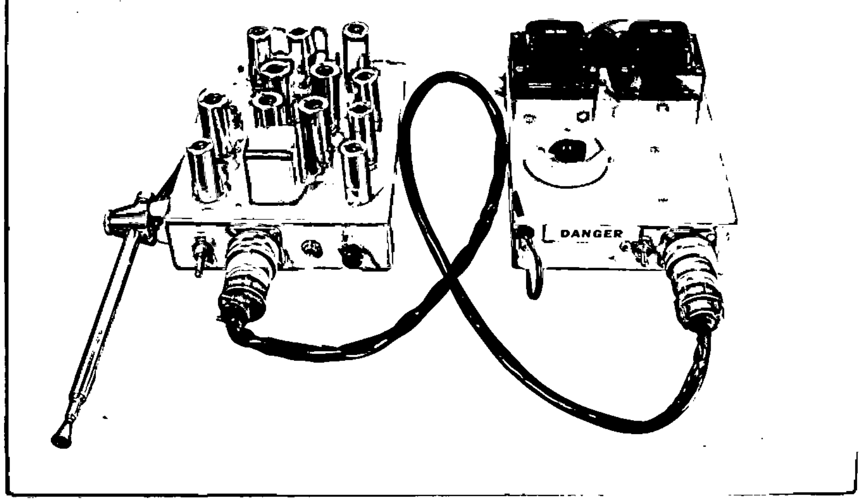


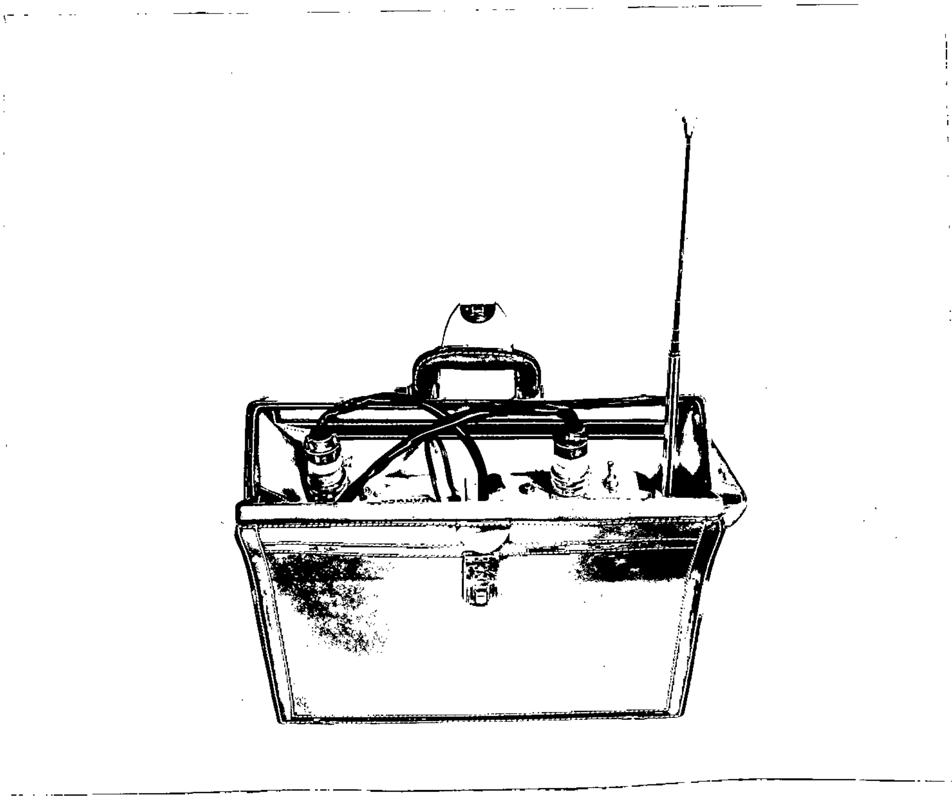
FIG. 2 - PULSE DURATION MODULATED RECEIVER - NOISE MASKING

FIG. 2



PULSE DURATION MODULATOR

TRANSMITTER

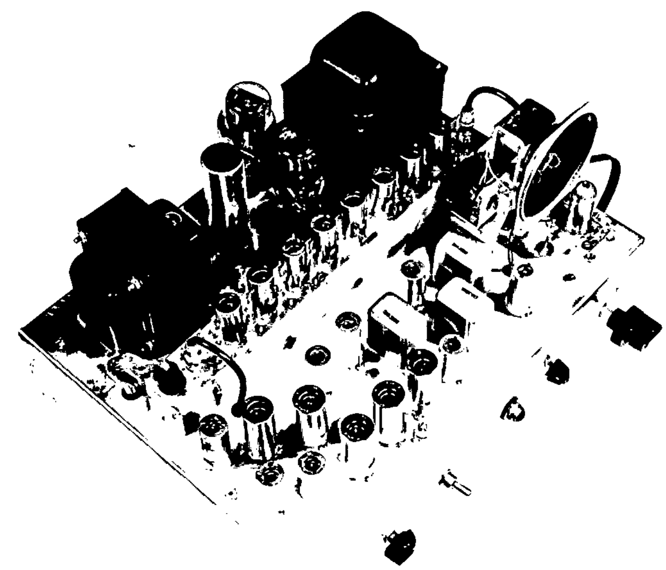


PULSE DURATION MODULATOR

TRANSMITTER

IN

CARRYING CASE



PULSE DURATION DEMODULATOR

RECEIVER